

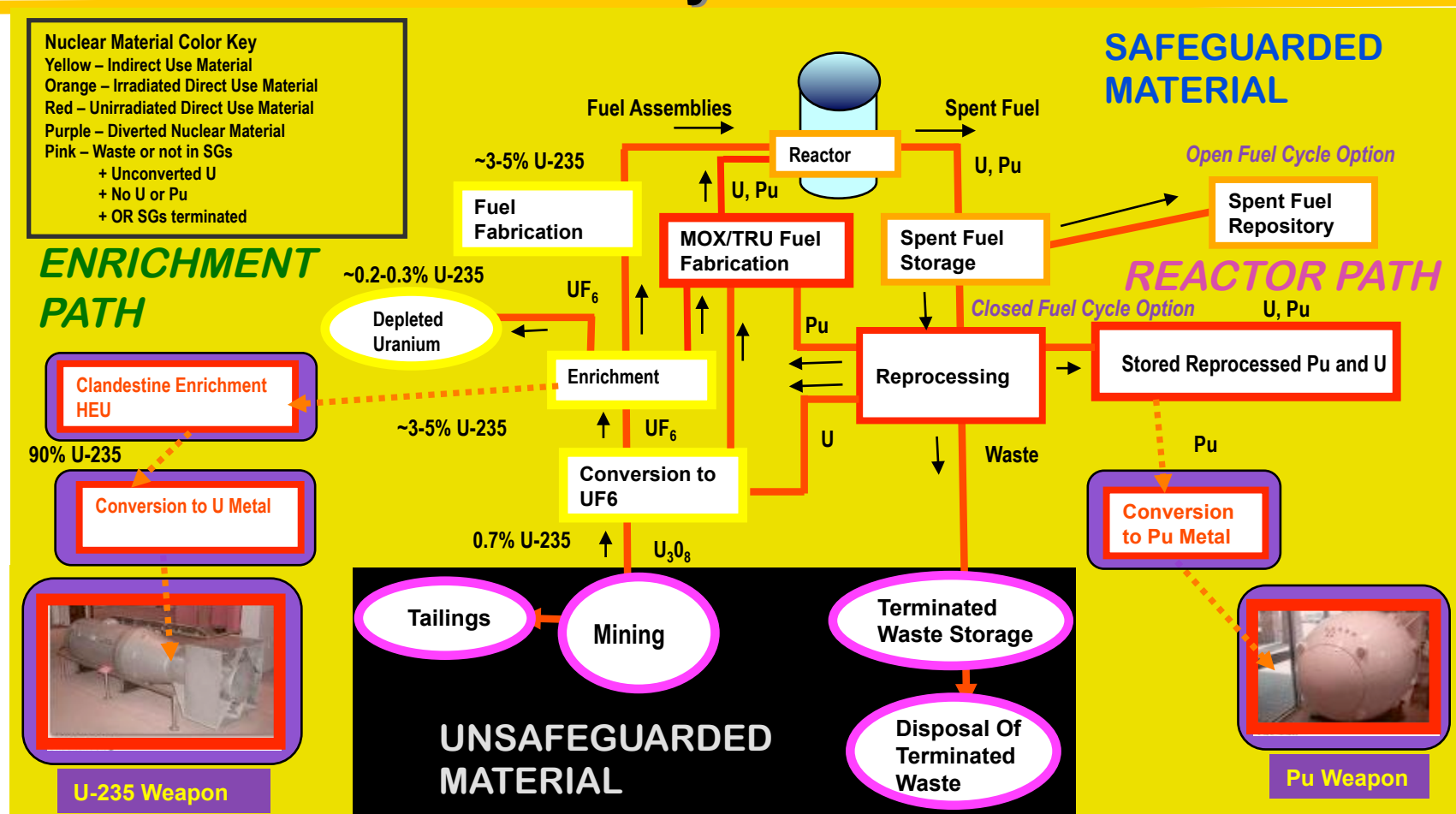
IAEA Verifications at an Uranium Enrichment Plant

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Nuclear Fuel Cycle – Proliferation Aspects

Enrichment – Key to the Uranium Path



Centrifuges – 21st Century Technology for Enrichment

Why Such Proliferation Concerns/ Int'l Headlines?

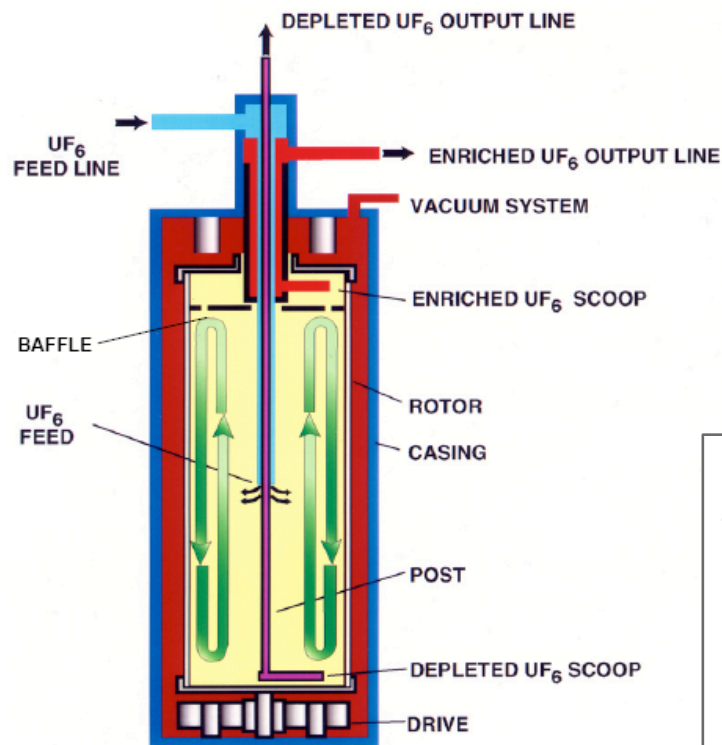
- **Small footprint compared to GDP – energy use and size**
 - Clandestine plants – possible and likely!
 - Harder to detect than GDP! 1/50th the electrical consumption – less waste heat
- **Compact size of centrifuges – 1-3m tall / 0.5m dia**
- **Small specific inventory / Short equilibrium time**
 - Can change from LEU to HEU production far quicker than GDP
 - Timeliness a concern
- **Technology was limited to certain NWS and stable NNWS**
 - Khan network starting in Pakistan changed this status quo
 - IAEA DG El-Baradei comment – “Nuclear Wal-Mart”
- **Bush Administration – PSI generated by concerns about GCEPS technology**
- **NSG – Trigger List Items – Dual Use**
- **LIS may be technology of the future but GCEPs work NOW!**

Safeguards Concerns at LEU GCEPs

Three Basic Diversion Scenarios

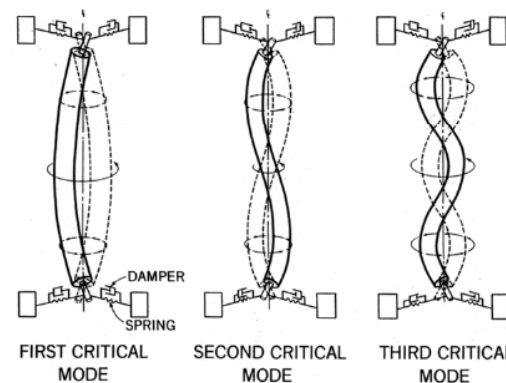
- **Production of a SQ of undeclared HEU ($\geq 20\%$ U-235)**
 - Misuse of plant to gain HEU for weapons program
- **Diversion of a SQ of declared LEU, NU, or DU**
 - Take declared material for weapons program
 - Enrich in clandestine plant
- **Production of LEU in excess of declared amounts**
 - Take undeclared material / enrich for weapons program
 - Enrich in clandestine plant

What Is a Centrifuge?



Schematic of Gas Centrifuge

MODE SHAPES OF FIRST THREE FLEXURAL CRITICALS OF A CENTRIFUGE ROTOR



Separative work unit (SWU) = function of the amount of uranium processed, the composition of the starting material, and the degree to which it is enriched; it is proportional to the total machine operation time required to achieve this, but is defined independent of the enrichment technology.

Separative work = SWUs, kg SW, or kg UTA (from the German *Urantrennarbeit*)

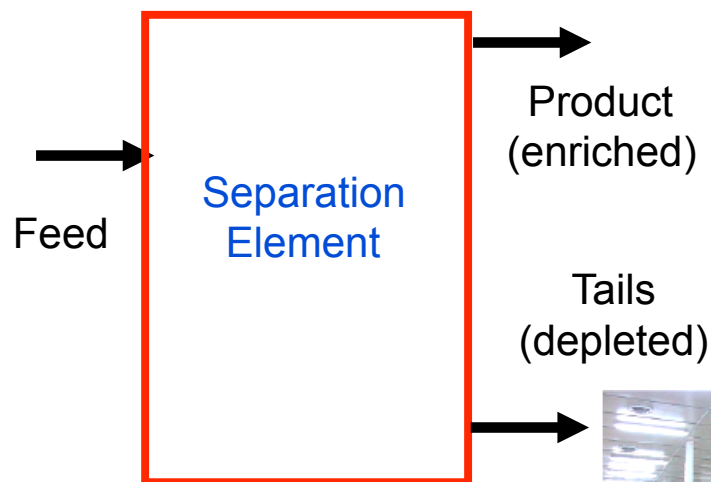
1 SWU = 1 kg SW = 1 kg UTA

1 kSWU = 1 tSW = 1 t UTA

1 MSWU = 1 ktSW = 1 kt UTA

Centrifuges and Cascades – Theory (Plus Example)

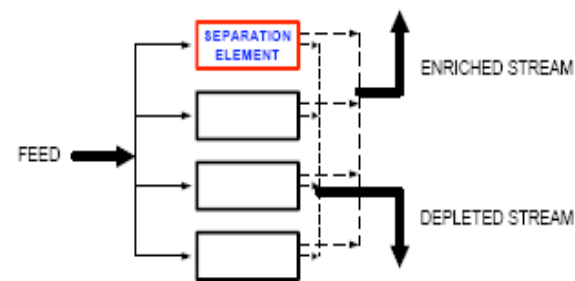
Single Centrifuge



**Key Rule of Thumb ~5000
SWU to make 1 SQ of
HEU from Nat U**

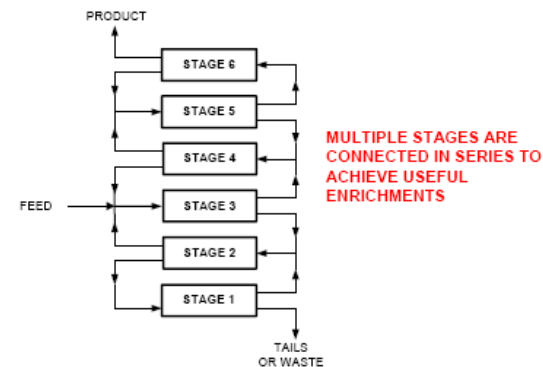
Centrifuges in Parallel

SEPARATION ELEMENTS MAY BE
CONNECTED IN PARALLEL TO ACHIEVE
HIGHER THROUGHPUT



Cascade

THE DEFINITIVE CHARACTERISTIC
OF A STAGE IS THAT IT CARRIES THE
ENTIRE THROUGHPUT OF THE
CASCADE AT THE COMPOSITION OF
THAT STAGE



**MULTIPLE STAGES ARE
CONNECTED IN SERIES TO
ACHIEVE USEFUL
ENRICHMENTS**



**Cascade
at Natanz**

What is a UF₆ Cylinder

Where Inspectors Find/Verify U and U-235 Material

30B Product (2.5 ton)- Product



48G (14 ton) - Tails



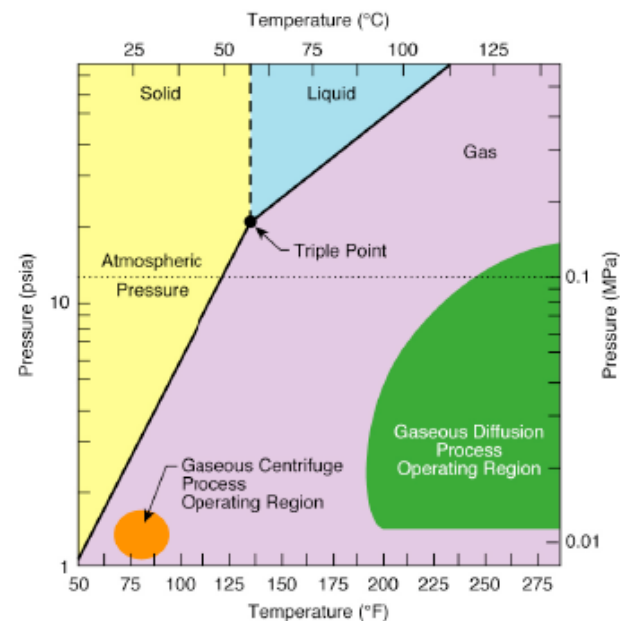
48Y (14 ton) - Feed



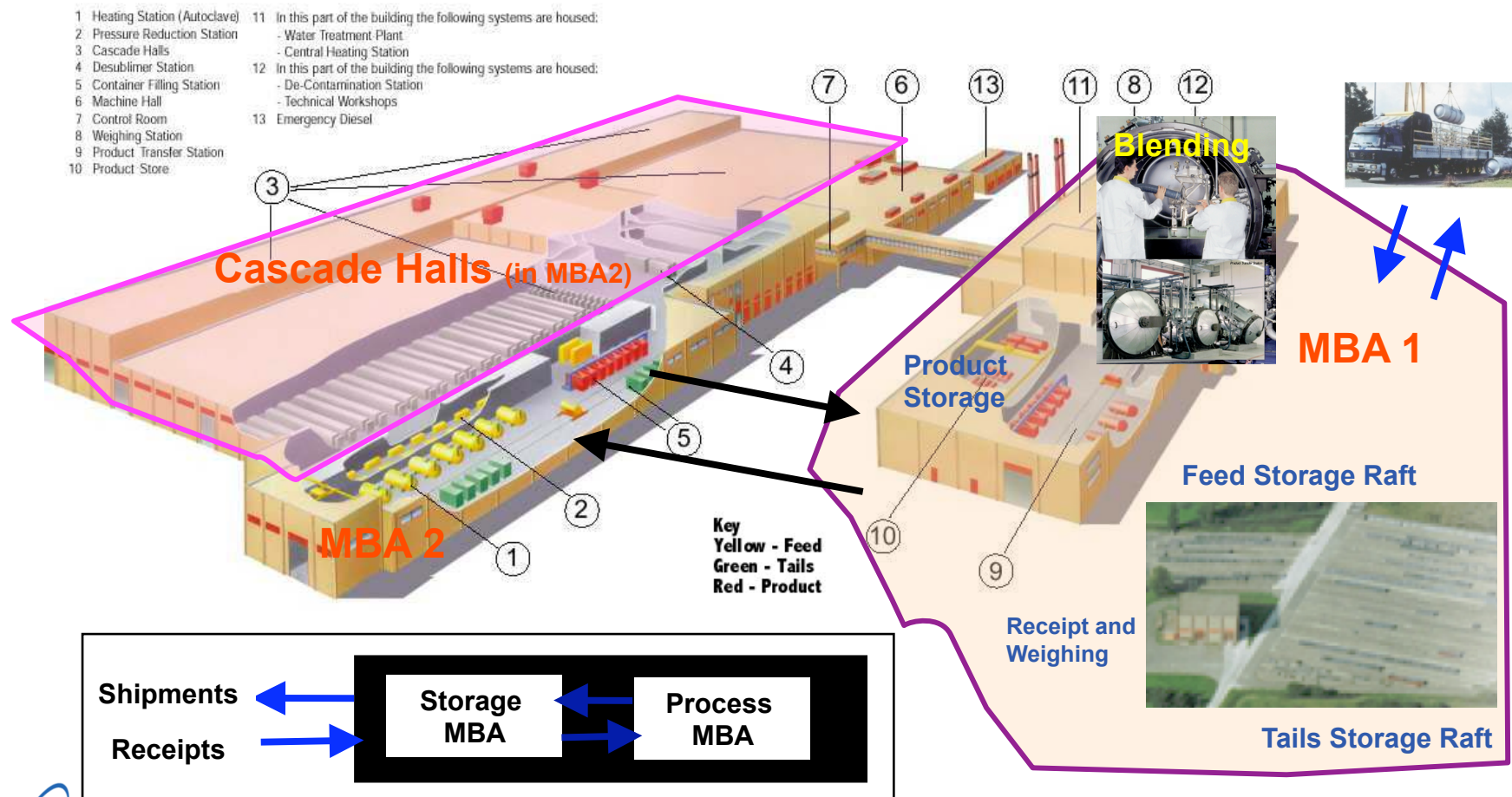
5a (25 kg) - HEU



UF₆ PHASE DIAGRAM



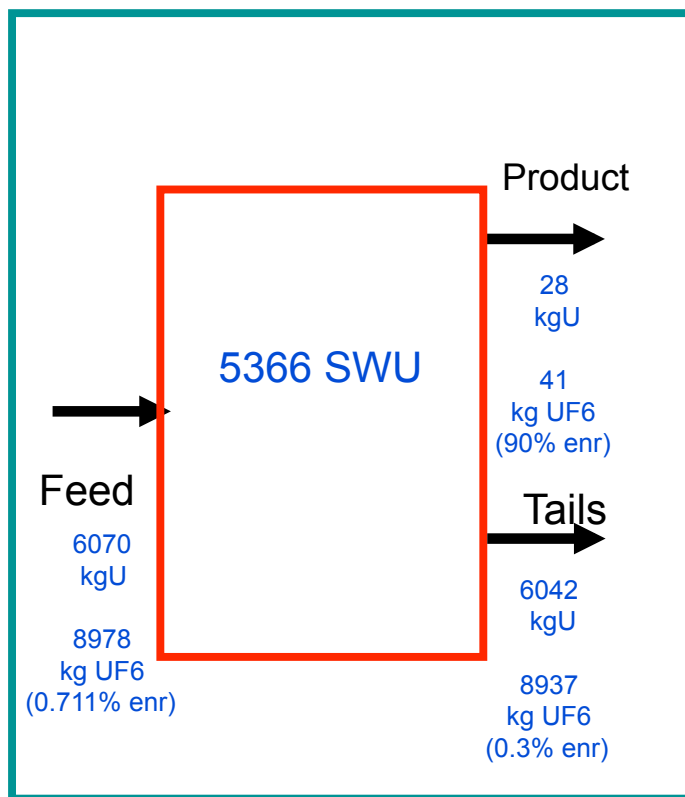
Gas Centrifuge Enrichment Plant (GCEP) Process Areas



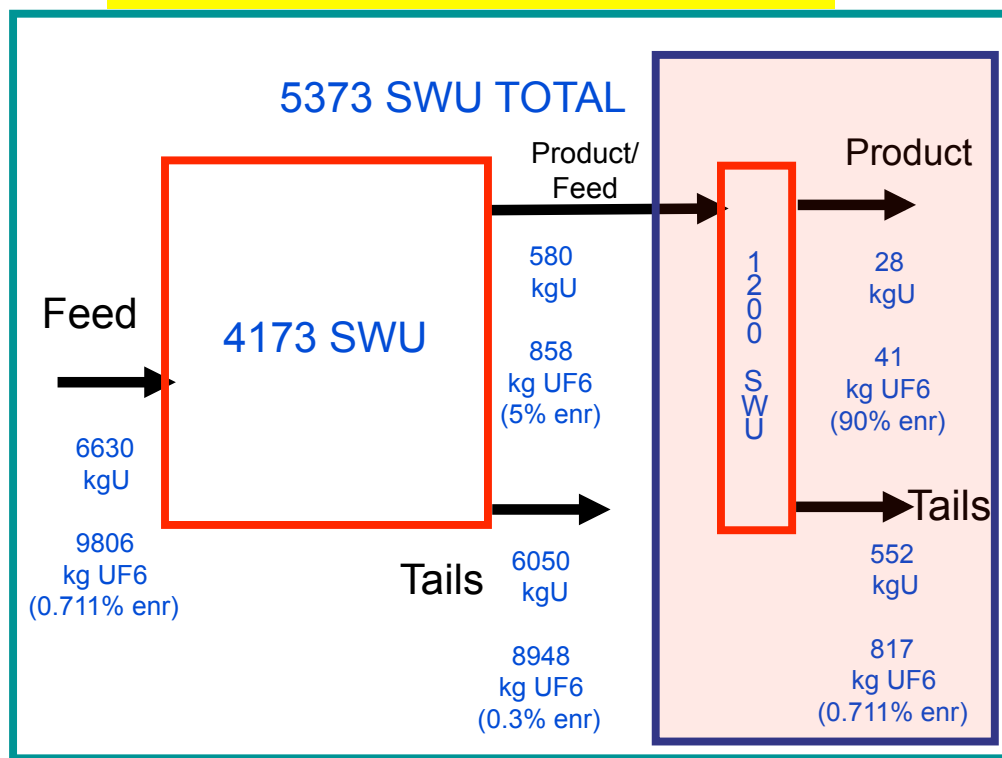
Centrifuges and Cascades

Proliferation Scenarios

Single Facility – NU-to-HEU



Declared LEU Facility and Clandestine HEU Facility – NU-to-LEU/LEU-to-HEU



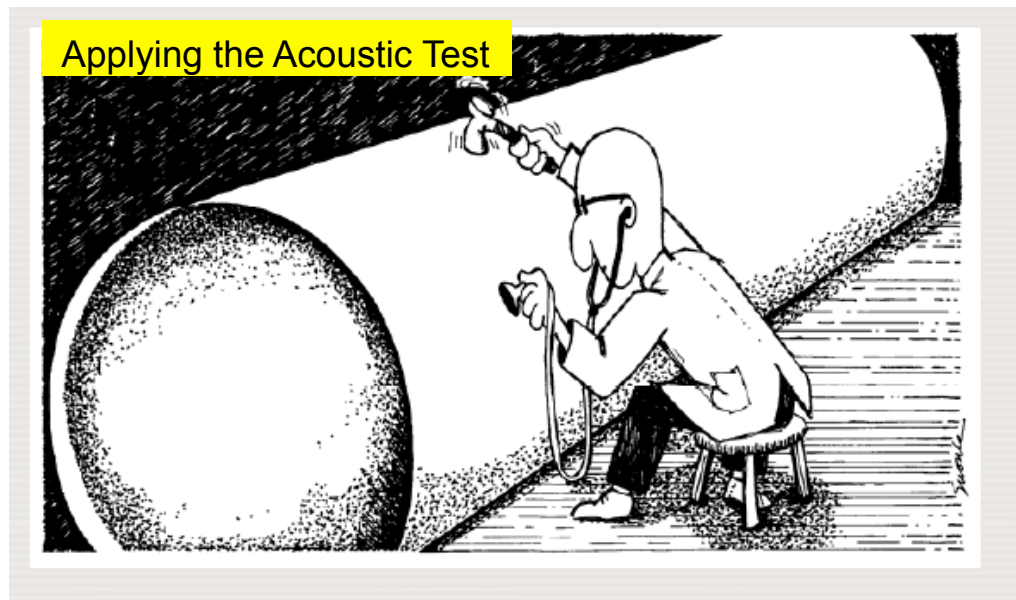
IAEA Detection Goals

What Shall We Focus on Verifying and How

- Detection of HEU ($\geq 20\%$ U-235) Production
 - Detect 25 kg U235 in U in one month
- Detection of Diversion of LEU ($< 20\%$ U-235)
 - Detect 75 kg U235 in U in one year
- Detection of Diversion of NU and DU
 - Detect 75 kg U235 in U in one year

IAEA Accountancy Verification Methods GCEPS Application

- Three levels of defects to detect with NDA Instruments – Key concept
 - *Gross defect*
 - *Partial defect*
 - *Bias defect*
- Examples in GCEPS:
 - *Gross defect*
 - **No U present**
 - *Partial defect*
 - **Lower ^{235}U content**
 - **Part of U missing**
 - *Bias defect*
 - **Lower ^{235}U content bias**



Hexapartite Safeguards Project (HSP)

Historical Background on Key GCEP SG Developments

- HSP convened
 - Establish an effective and efficient safeguards approach for LEU GCEPs
 - Under INFCIRC/153-type agreements
 - Study lasted from November 1980 to March 1983

- Participants included
 - US
 - Japan
 - Australia
 - UK, Germany, Netherlands
 - “The Troika”
 - IAEA and Euratom



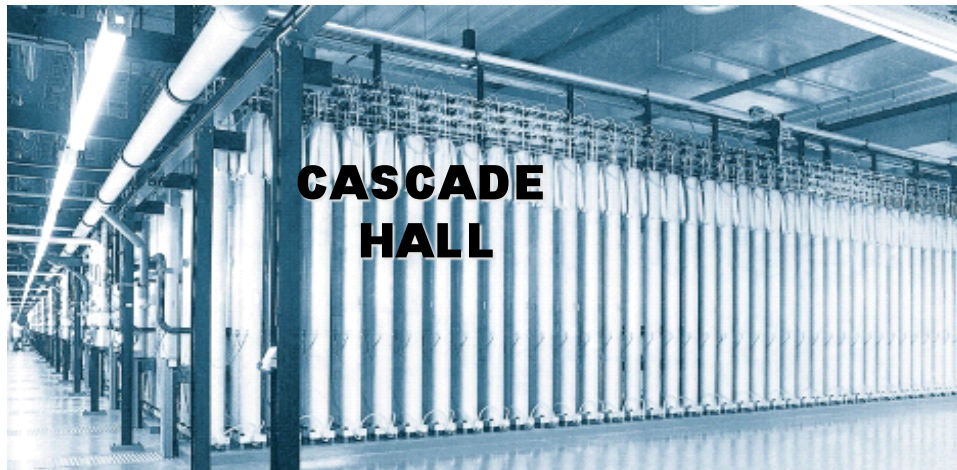
HSP Resulting Guidance Resulting Tensions

- Established SG approach that is still backbone of current SG Criteria
- Measures outside cascade halls to detect diversion of uranium
- Measures inside cascade halls-detect HEU production-Use LFUA
- Operator – holds feed, product, and tails cylinders for verification
- HSP did not address question of undeclared feed
- Operator, State, Inspector Tension – from HSP to today and beyond...
 - Operator wary of inspector “espionage” – giving up trade secrets
 - Secret data – national concerns
 - Proprietary information – operator industrial competitiveness concern
 - Proliferation sensitive information
 - Operator fighting against access by inspectors and technology
 - Costs to NNWS operator give competitive edge to NWS operator

Design Information/LFUA Concern

Example of Operator Misuse of Cascade for HEU Production

- Low Frequency Unannounced Access (LFUA) Inspections



- Access is on a random, unannounced basis
- Access must be provided within 2 hours of request
- Performed 4 -12 times per year (facilities <1000MTSWU/yr)
- Protection of proprietary information by negotiated procedures

Measures to Detect Undeclared HEU Production

LFUA - Verification Measures include:

- Visual observation
 - Detect presence of unreported F/W equipment within cascade areas
 - Detect piping changes indicative of connecting cascades in series
 - Any 5A cylinders sitting around?
- NDA measurements on header piping
 - Cascade Enrichment Header Monitor (CEMO)
 - Detects HEU
 - Only operates at Capenhurst (QCAX)
- Obtaining of UF₆ samples from cascade
 - Analyze for enrichment
 - Rare and unwelcome event!
- Obtaining of environmental samples; analyze for enrichment



Environmental Sampling (ES)

- Potentially a very powerful technique
- Baseline samples need to be taken
- Field trials have occurred
 - Including sampling inside cascade halls
- Can detect increasing enrichments as cascades brought on line
 - Peter Friend (URENCO) confirmed this statement
- Operators did not take special measures to prevent UF_6 releases



IAEA Measures to Detect Diversion of Uranium

- Inspection regime includes:
 - Annual PIT/PIV
 - 11 monthly interim inspections for flow verification
 - IAEA verifies feed, product, and tails cylinders - receipts and shipments
 - OPERATOR holds feed before feeding to process
 - OPERATOR holds tails and product before shipment off-site
- Auditing of records and reports (ICR, PIL, MBR)
- Verification of nuclear material quantities (flows and inventories)
- Material balance evaluation
- Application of seals to UF₆ cylinders

Verification of Nuclear Material Quantities

- **Inventories at PIV**

- UF_6 cylinders in storage yards
- UF_6 cylinders
 - Connected to cascades
 - In process vessels (F/W stations)



- **Flows at Interim Inspections and PIV**

- Feed, product and tails UF_6 in cylinders
- Minor waste streams (trap material, etc.)



Verification of UF₆ Feed – Product - Tails

- **Weights of UF₆ Cylinders**

- Verify weight of full cylinder by:
 - IAEA load-cell system (LCBS)
 - Authenticate operator scales
 - ❖ Use IAEA check weight
- Can weigh cylinders to about 1-5 kg
- Empty cylinder weights usually not verified



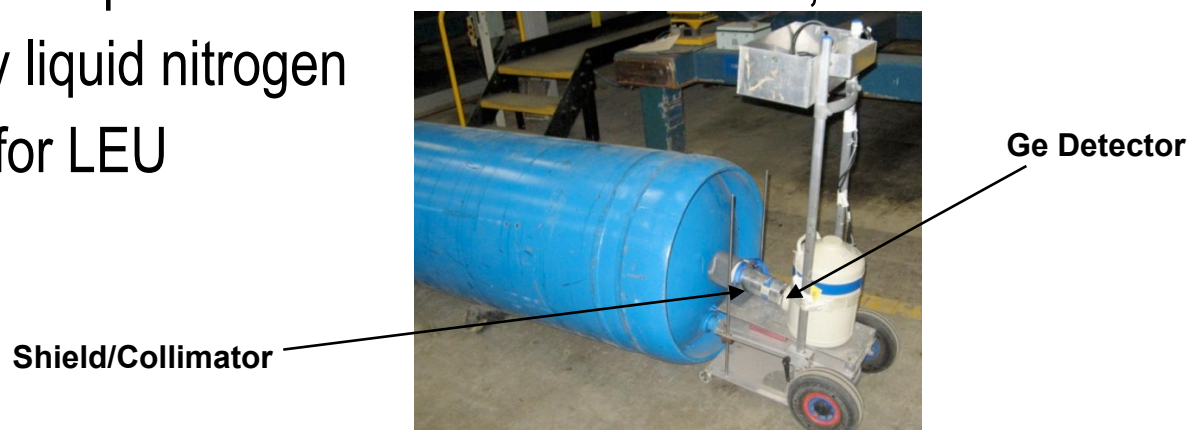
- **UF₆ Enrichment Measurements**

- Gamma Ray NDA - determine enrichment at gross- and partial-defects level
- Sampling and DA – determine enrichment at bias-defect level

Instruments for Gamma-Ray NDA Measurements

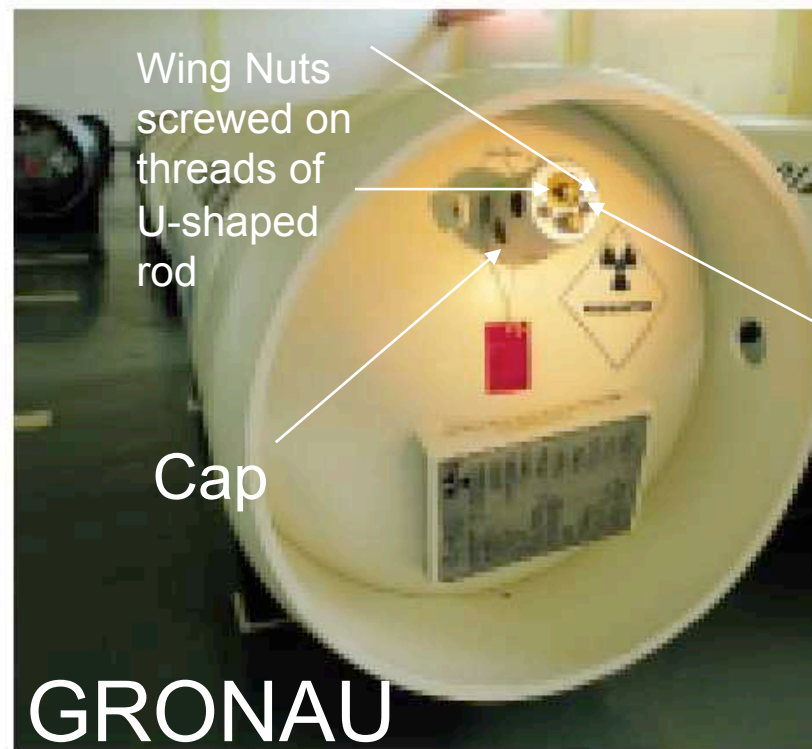
Power and Limits of the Technology

- **NaI(Tl)/PMT (MMCN)**
 - Usually used for NU feed and DU tails
 - $\delta_2 \sim 10\text{-}20\%$ for NU
 - $\delta_2 \sim 25\text{-}50\%$ for DU
- **HPGe (MMCG) + ultrasonic thickness gauge (ULTG)**
 - Used for LEU product and sometimes for NU, DU
 - Cooled by liquid nitrogen
 - $\delta_2 \sim 5\%$ for LEU



Example of Sealed LEU Product Cylinder

Maintaining “CofK”



GRONAU

Inspected and Sealed Product-Container

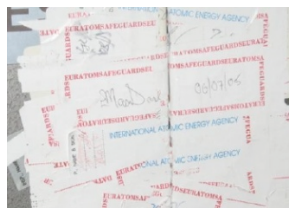
Sampling and DA of UF₆

- Physical sample UF₆ → IAEA selects cylinder – operator samples
- Samples to IAEA Safeguards Analytical Laboratory – at PIV
- U-235 concentration by Thermal Ionization Mass Spec (TIMS)
 - ITV Values for uncertainty for TIMS

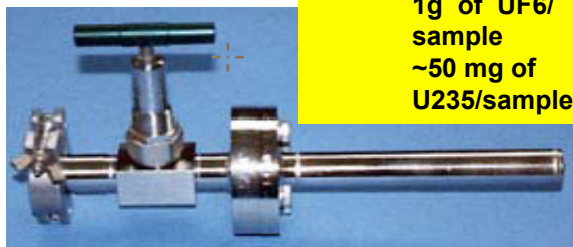
➤ $\delta_3 = 0.1\%$ for LEU

➤ $\delta_3 = 0.2\%$ for NU

➤ $\delta_3 = 0.5\%$ for DU



Sealing the Cabinet



1g of UF₆/sample
~50 mg of U²³⁵/sample



Taking a DA Sample

Beyond HSP - HSP+ and Other Approaches Outlined

Variations on HSP for Other GCEPs

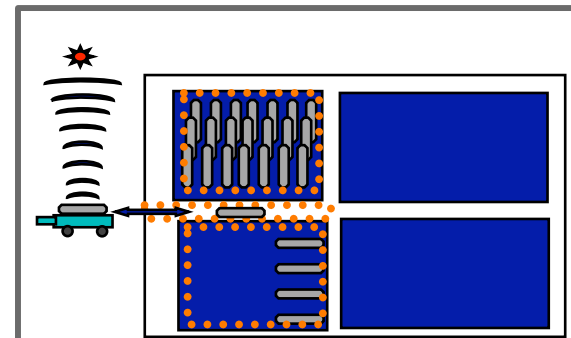
- **Japan (Rokkasho)**
 - Laser cylinder ID system field trial, PNUH measurements, ELFUA + CHEM + ES
- **Urenco (Almelo, Gronau, Capenhurst)**
 - Proposed enhanced safeguards approach for Almelo, SNRI(with mailbox)
 - Random interim flow verification (of European Community (EC) inspections)
- **France (George Besse II)**
 - Discussions on safeguards approach and measures
- **Brazil – Resende (current <10 tSWU)**
 - Camera/visual observations on piping, gamma and neutron measurements on enclosures, DA samples
- **Iran**
 - Traditional safeguards measures and Visual observation and C/S
- **China**
 - FEM - on product headers, Koshelev filter – Particle filter for environmental sampling
 - VMOSS -Integrated camera and seal system, Camera surveillance on feed and withdrawal stations

Future Safeguards Measures

Introducing Process Monitoring Technology – Pro/Con

- **Partial Defect verification - each cylinder**

- Centralized “Cylinder Portal Monitor”
- Distributed systems
 - The cylinder identification (ID)
 - ❖ RFID
 - ❖ Laser ID - thumbprint
 - Gross weight
 - Enrichment of U in UF₆
 - Load Cells and/or operator accountancy scales



- **Surveillance of UF₆ handling area**

- Track cylinders – “item count” into/out of process
- Accountancy complement/CofK



- **Electronic seals**

- On product and tails cylinders leaving process
- If deemed necessary



Summary of GCEPS Safeguards

- GCEPS safeguards – manpower intensive
- Desire to close gaps on undeclared feed
 - Operator “no one would ever divert undeclared LEU product”
- Mailbox and SNRI – results from trials at Gronau – “1st next step”
- Unattended monitoring system – in development
 - UNARM – flow (mass) and enrichment
 - Process Monitoring – tap into operations
 - RFIDs/Laser ID – follow cylinders
- Sensitive technology!



Centrifuges From
Libya